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Tackling the relevance of packaging in life cycle assessment of virgin olive oil and the environmental consequences of regulation

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ABSTRACT

Production and consumption of olive oil is very important in Europe, being this product a basic element in the Mediterranean diet since long ago. The project objective is two-fold: a study of the contribution of virgin olive oils (VOOs) usual packaging to the whole life cycle of the product and a study of the environmental consequences of the Spanish Government regulation on VOO packaging. A life cycle assessment (LCA) according to ISO 14044 has been performed using the CML methodology for the impact assessment.

The results show that the packaging influence varies from 2% to 300%, depending on the impact category and type of packaging (glass, tin or polyethylene terephtalate). Glass, which is related to higher quality perception by consumers, was found to be the most influencing material (due to its weight); however, this

impact may be fairly reduced by applying ecodesign strategies (such as weight reduction and recycled-glass percentage increase).

A new Spanish regulation on the mandatory use of non-refillable oilers in HORECA establishments (hotels, restaurants and caterings) aims to provide more quality assurance and better information to consumers; however, it was also found to mean a 74% increase in greenhouse gases emissions. This regulation was deeply discussed at European level and its application was withdraw due to consumers rejection, except for Spain.

The findings of the present case study show that LCA and ecodesign should be important tools to be promoted and applied in policy making to reduce non-desirable consequences of regulation.

Key words: life cycle assessment, carbon footprint, ecodesign, policy making, glass, tin and polyethylene terephtalate, HORECA.

1. Introduction

Olive oil has been essential to the Mediterranean diet since long time ago. It is widely appreciated in Europe, which produced 70% and consumed 56% of olive oil in the world in the last five years (2012-2016) (EU Comission, 2018). Nevertheless, more recently, many other countries around the world are increasing their consumption due to its beneficial contribution to human health (ie. prevention of cardiovascular risk and prevention of some cancers, according to Assman et al., 1997).

Olive oil is one of the most important agri-food products in Spain, the first producing country of olives and olive oil in the EU. Spanish olive oil production is exported mainly to Italy, USA, Japan and Australia (MAPAMA, 2017a).

The European Denominations of Origin (DO) guarantee the quality and origin of some agri-food products (Council Regulation (EC) 510/2006). In Spain, there are 29 DO of extra virgin olive oil (EVOO) (MAPAMA, 2017b). A classification of different olive oil types depending on their quality (extra virgin olive oil, virgin olive oil and general olive oil) is shown in Table 1, according to international standards

(Council Regulation, (EC) 1234/2007; Codex Stan 33-1981). In this document, when referring to virgin olive oils (VOOs), we mean both EVOO and VOO, which are meant for human consumption (see Table 1).

Table 1. Types of olive oil depending on their quality (Sources: Council Regulation, (EC) 1234/2007; Codex Stan 33-1981)

Name: GENERAL	Name: SPECIFIC	Definition
Virgin olive oils (VOOs)		Obtained from the olive tree fruit, solely by mechanical or other physical procedures, without product alteration or mixture with other types of oils.
	Extra virgin olive oil (EVOO)	Virgin olive oil with a maximum free acidity [(1)] 0.8g/100g.
	Virgin olive oil (VOO)	Virgin olive oil with a maximum free acidity [(1)] 2.0g/100g.
	Lampante olive oil	Virgin olive oil with a free acidity more than [(1)] 2.0g/100g. Not for human consumption.
Olive oils (OOs)	Refined olive oil	Obtained by refining [(2)] lampante olive oil. Maximum free acidity [(1)] 0.3g/100g.
	Olive Oil "ordinary"	A blend of refined and virgin olive oils (except with the lampante) in different proportions. Maximum free acidity [(1)] 1.0g/100g.
Olive pomace oils (OPOs)	Crude olive-pomace oil	Obtained from olive pomace[(3)] by treating it with solvents or physical procedures (usually it corresponds to the lampante olive oil), excluding the oil obtained by a re-esterification process.
	Refined olive-pomace oil	Obtained by refining crude olive-pomace oil. Maximum free acidity [(1)] 0.3g/100g
	Olive pomace oil	A blend of refined olive-pomace and virgin olive oils (except with the lampante) in different proportions. Maximum free acidity [(1)] 1.0g/100g

(1) Unit of measure: expressed as oleic acid.
(2) Refining: physical and/or chemical processes divided in a series of steps totally or partially to follow: degumming, neutralization, bleaching, deodorization and wintering (De la Osada., 2010)
(3) Solid by-product after the extraction of olive oil, formed by bones, skins, water, etc

The Single Market of Green Products Initiative[1] is a good example showing that agri-food products are on the spot of European sustainability policies or instruments, as half of its pilot projects are related to this sector. This one and many other instruments bring companies and organizations to adopt a sustainability strategy (mainly environmental related) to differentiate themselves from their competitors and to achieve a responsible and high quality image. Packaging has a significant influence in the environmental impact of many agri-food products (Flanigan et al., 2013; Ingrao et al., 2015), and it is an important component for distribution, storage, product quality protection and image.

[1] http://ec.europa.eu/environment/eussd/smgp/

As it happens within the Initiative cited above, Life Cycle Assessment (LCA) is one of the most commonly used methodologies to evaluate sustainability from the environmental perspective. LCA is a standardized environmental tool which evaluates a product along its whole life cycle (from cradle to grave) and includes in this evaluation a number of impact categories (ISO 14040, 2006; ISO 14044, 2006). This methodology has been used to evaluate packaging options (Heijungs and Guinée, 1995; Raugei, et al., 2009) and food supply chains (Jones 2002; Pelletier & Tyedmers, 2008; Pelletier, et al., 2008; Beccali, et al. 2009; Notarnicola et al., 2015).

In the olive oil sector a literature review (Banias et al., 2017) of the life cycle impacts of this product was published (from 1996 to 2015), showing only 18 LCA papers out of 98. Most of the published LCA studies refer to the farming and production processes, without much detail on the importance of packaging (Banias et al., 2017). Only few of them contain LCA-inventory data of olive oil: from just the agricultural stage (De Gennaro et al., 2012; Russo et al., 2016) or including also the oil making stage (Papadakis et al., 2006; Avraamides et al., 2008; Salomone et al., 2012). The literature including the packaging and distribution stages deals only with greenhouse gas emissions (Özilgen et al., 2011; Rinaldi, et al., 2014; Pattara et al., 2016). Detailed information of olive oil making and waste management in Spain can be found in (SCP/RAC, 2000). The present paper builds upon the existing literature by quantifying the environmental impacts of alternative packaging in a global VOOs supply chain. There is only one similar paper published recently (Accorsi et al., 2015), which compares glass vs plastic primary packaging for olive oil. The authors conclude that the bottling and the distribution phases impact significantly across the VOO life cycle. The difference with the present paper is that here a third type of packaging (tin or steel can) is also studied, sensitivity analysis of bottle weight influence is performed and lower distances for transport and distribution are considered (inside Spain instead of all over the world).

Olive oil is an essential component in the Mediterranean diet, known for its positive impact on health. If this diet is ever measured according to its impact on the environment and its relation to human health, such as some studies for Chinese diets (Song et al., 2016), complete olive oil information will be essential. If not the complete diet, many Mediterranean food products use VOOs and start to perform LCAs of both the product and the packaging, such as for anchovies (Laso et al., 2017).

On the other hand, there is specific food packaging regulation at EU level to preserve consumer's health, for example the food contact materials regulation (EC 1935/2004), supported by other specific regulations adopted for some materials, like the one for plastics (EC 10/2011). In addition, there is also EU legislation on food information to consumers (Regulation (EU) 1169/2011), where the origin labeling of unprocessed food (traceability) is one of the aspects to be included for quality and safety reasons (ie., for olive oil, Regulation (EU) 29/2012).

Related to this EU legislation, in the year 2014, a Spanish regulation (Real Decreto 895/2013, RD from here on) was approved to guarantee the olive oil quality in Hotels, Restaurants and Catering supply chains (the so called HORECA supply chain). This regulation states that: "In hotel and restaurant establishments and in catering services, olive oil shall be made available to the final consumer in labeled containers and provided with an opening system that loses its integrity after first use. A packaging that, by its characteristics, can be made available to final consumers more than once, will also have a protection system to prevent its refilling after the original content has been exhausted." The aim of this regulation was to provide more quality assurance and better information to the consumer. This regulation, requiring that olive oil "presented at a restaurant table" must be in factory packaged bottles with a tamper-proof "hygienic" nozzle and printed labeling, was proposed in 2013 at EU level and submitted to public consultation, provoking popular loathing from the people that in theory it aimed to protect for their own good. It was a measure intended to help consumers, to protect and inform them but it was clear that it didn't attract consumer support, so as a consequence, EU withdraw the proposition (Telegraph, 2013). Even so, Spain implemented this regulation in 2014.

The application of this regulation, according to Spanish hospitality sector, has different consequences. They state that the price of the olive oil in HORECA increased about 7 times, due to both the much higher price of small glass bottles compared to the previous bigger packaging and the higher quality of olive oil bought nowadays (InfoHoreca, 2016).

The aim of the present paper is two-fold: to evaluate the environmental impact associated with different types of packaging for VOOs and to evaluate and discuss some environmental consequences of the RD in Spain.

(i) Evaluate the environmental influence of the packaging in the life cycle of VOOs, comparing the three most commonly used (Linares et al., 2006) types of packaging, based on glass, polyethylene terephtalate (PET) and tin. Recommendations on the packaging design will be also made.

(ii) To check the environmental consequences due to the new Spanish regulation (RD 895/2013) in the impact of VOOs consumption in HORECA. A preliminary calculation of global warming potential impact will be presented in this paper.

2. Materials and methods

2.1. LCA methodology

Life Cycle Assessment (LCA) is described in the standards ISO 14040:2006 and ISO 14044:2006. Environmental aspects are quantified all along the life cycle of a product or service and the associated potential impacts are evaluated. The aim of an LCA is measuring, as a fundamental step for improvement.

Four LCA phases are necessary for a complete study, according to the ISO 14044: goal and scope definition, inventory analysis (LCI), impact assessment (LCIA) and interpretation of the results. In LCIA, some impact categories (indicators) are calculated according to a chosen methodology. In the present study, the CML 2001 (updated 2015) LCIA methodology (Guinée, et al., 2002) was used and the following impact categories were evaluated: Abiotic Depletion Potential (ADP elements), Abiotic Depletion Potential (ADP fossil), Acidification Potential (AP), Eutrophication Potential (EP), Freshwater Aquatic Ecotoxicity Potential (FAETP inf.), Global Warming Potential (GWP 100 years, excl. biogenic carbon), Human Toxicity Potential (HTP inf.), Marine Aquatic Ecotoxicity Potential (MAETP inf.) and Terrestrial Ecotoxicity Potential (TETP inf.). Additional to these impact categories, two more indicators were calculated: the primary energy demand (Frischknecht, et al., 1998) total and from non-renewable resources (net calorific value) and blue water consumption (Berger & Finkbeiner, 2010).

For the second part of this study, checking the environmental consequences due to the new Spanish regulation (RD 895/2013), only GWP is being used, as a proxy for this preliminary assessment.

The LCA was modeled in GaBi software (Thinkstep, 2015). The databases used were GaBi professional 2015 and Ecoinvent 3.0.

2.2. LCA System description

All major material and energy flows and water use associated with the life cycle stages of VOOs product, such as olive production, virgin olive oil making, packaging, distribution and end of life (see Figure 1) have been included within the system boundary.

Inventory data of olive production and virgin olive oil making stages has been obtained after making averages from two Spanish case studies published in the literature (SCP/RAC, 2000; ECOIL, 2006). Olives production efficiency has high variations depending on climate of the area, type of trees cultivated, pests, etc. (Rinaldi, et al., 2014). Consequently, Spanish data will be used in this study, although more recent data from other countries can be found in the literature (Avraamides et al., 2008; De Gennaro, et al., 2012; Salomone et al., 2012; Rinaldi, et al., 2014).

For the packaging component, direct data has been obtained from the most commonly used types of packaging for VOOs in the market (an average weight of the different materials for a 500 mL bottle was obtained from sets of 10 samples of bottles per material). The samples were obtained from supermarkets, and chosen among the most commonly sold trademarks in Spain.

The distance from Jaén (main VOOs producer province in Spain) to Madrid and Barcelona (main logistic centres) has been used as the average distribution distance from the oil mill to the selling-store. The distribution stage impact is affected by the type of packaging used mainly due to differences in their weight.

The end of life scenario[2] used implies that part of the packaging is recycled and the rest goes to landfilling facilities. The percentages to recycling or to landfilling (for each material) have been obtained from available information published by the Spanish green dot holders (see Table 7). The percentage of recycling packaging was modeled by including the burdens of the recycling process and the credits from the material obtained (using a system expansion methodology). For glass, no recycling-treatment data was available on GaBi databases, thus, the recycling process was included taking the average Spanish data from a previous project (FENIX, 2012), which was updated to GaBi professional 2015 (Thinkstep, 2015). In the case of tin and PET, the recycling processes for steel-can-scrap and plastic were respectively used. For all three packaging materials, credits from recycled material obtained (which avoids the corresponding virgin material production) were included. In the case of PET recycling, it was considered that the quality of the recycled material was lower than the quality of the virgin one. In this case, the economic value of recycled vs virgin PET, 0.6 (obtained from recycled and virgin prices, 0.87 €/kg and 1.45€/kg respectively, according to ANARPLA, 2015), was used as correction factor to the amount of impact avoided.

[2] There is an important ongoing LCA project in Spain to thoroughly study the end of life of packaging: the ARIADNA project. At the moment of writing this paper, its methodological decisions, data used and results have not been made public, so background data has been taken from literature and GaBi Database.

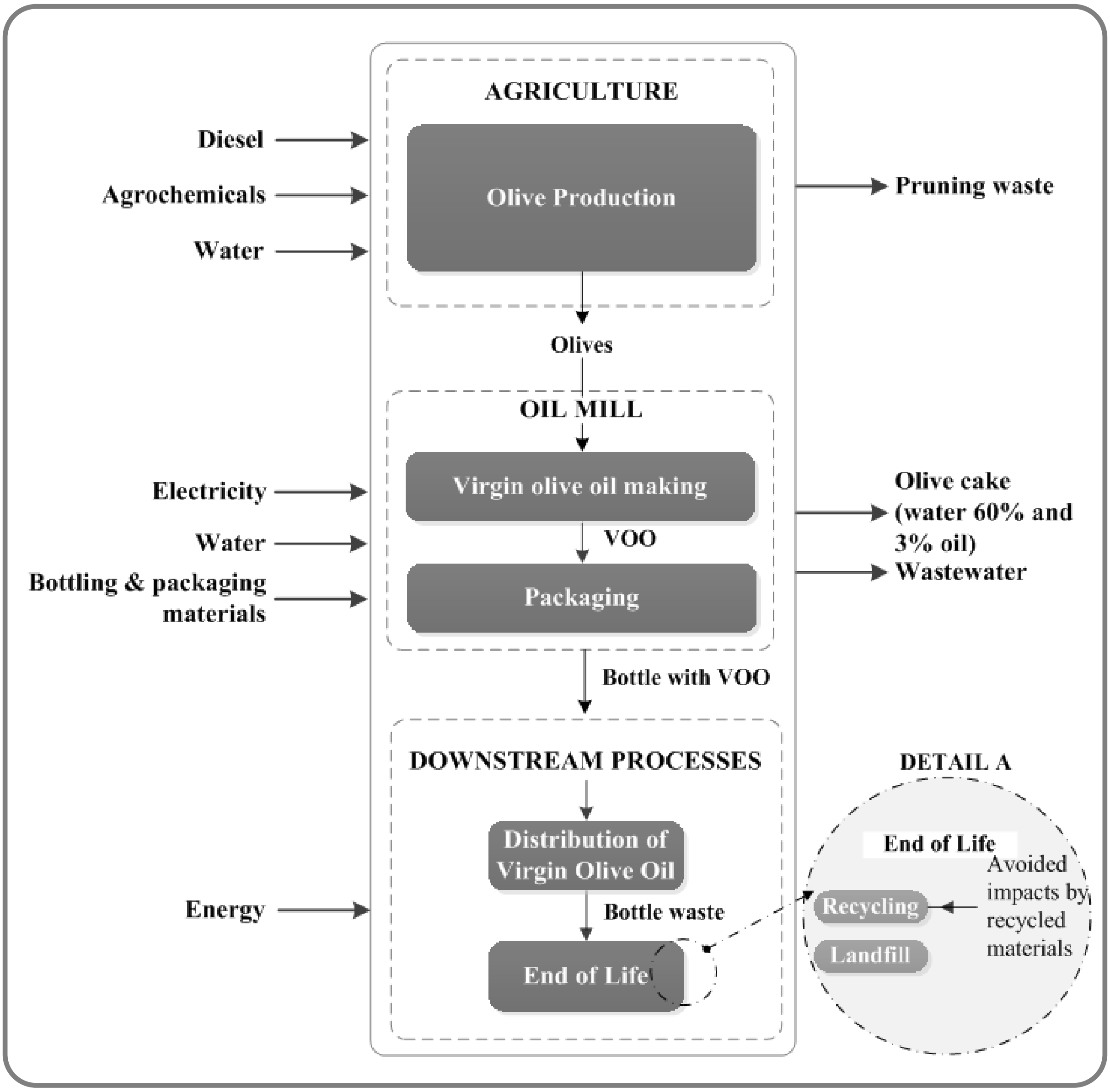


Fig. 1. System boundary of the virgin olive oil life cycle stages included in the study

2.3. Environmental consequences of non-refillable olive-oil-dispensers regulation for HORECA establishments

Primary data was collected through the use of questionnaires and personal communication with owners of restaurants, coffee-shops, snack bars, etc. These questionnaires had 3 parts: general information, information AFTER the application of the regulation and information BEFORE its application (type of packaging of VOOs and other aspects needed to assess the differences in environmental impact).

In this preliminary study, answers to the questionnaire from 20 restaurants were obtained and the results of these answers will be used to estimate the change in environmental impact of VOOs consumption (in the HORECA sector) due to the application of the non-refillable-VOOs-dispensers regulation in Spain. According to the statistical formula from Valdivieso et al., 2011, the confidence of this study, with 20 samples, is between 60-65% with an error of 10%, because the total population of restaurants (with CNAE[3] code 5610), which are under this current legislation, is 69192 restaurants (CAMERDATA, 2017). Therefore, to achieve 75% confidence level with a 5% error in the results, answers from a sample of 132 restaurants would be needed. In future projects, for a comprehensive and representative statistical analysis of these environmental implications, the number of restaurants to answer the questionnaire should be higher.

In order to calculate the environmental implications of this RD in Spain, the quantity of VOOs consumed per year in the Spanish HORECA sector is also needed and it has been calculated from different sources of information by following the procedure and hypothesis shown in Table 2. The amount of VOOs consumed per year in the hospitality sector was estimated to be about 56.97 ML. This amount could vary from one year to another and is not exact due to lack of direct data. Nevertheless, it is considered appropriate enough for the present study, because the calculated impact will increase/decrease proportionally with the amount of VOOs consumed.

Table 2. Steps followed to estimate the VOOs consumed in HORECA sector during one year.

Step	Data description	Data value	Reference	Comments
[1]	Consumption of Olive Oil (OO) in Spain in 2016 (domestic + hospitality sector)	548 580 789 L	IOC, 2017	OO density = 0.910-0.916 kg/L (Codex alimentarius, 2017)
[2]	Domestic vegetable oil consumed in 2014	594 232 910 L	MAPAMA, 2017c	Data. 2014
[3]	% Domestic Olive Oil consumed = EVOO+VOO+OO	69.5%	MAPAMA, 2017c	Data. 2014
[4]	% Domestic Extra Virgin Olive Oil (EVOO) consumed	18.4%	MAPAMA, 2017c	Data. 2014
[5]	% Domestic Virgin Olive Oil (VOO) consumed	10.8%	MAPAMA, 2017c	Data. 2014
[6]	Domestic OO consumed in Spain in 2014	412 991 872 L		Calculated: [2]*[3]
[7]	HORECA sector OO consumed	135 588 917 L		Calculated: [1]-[6], assuming that 2016 consumption is similar to 2014
[8]	% VOOs (EVOO+VOO) related to domestic OO consumed in 2014	42%		Calculated: ([4]+ [5])*[2]/ [6]
[9]	% VOOs (EVOO+VOO) related to hospitality sector OO consumed	42%		Same percentage as per domestic is assumed
[10]	**Hospitality sector VOOs consumed (EVOO+VOO)**	**56 966 854 L**		Calculated: [7]*[9]

[3] CNAE, Numerical Code of Economic Activity

3. Results and Discussion

3.1. *LCA of VOOs: packaging contribution*

In this section, the inventory data of the system under study will be presented as well as the environmental impact results and interpretation. Some suggestions for packaging improvement will be also discussed.

3.1.1.Inventory data

The chosen functional unit (FU) for the study was the “one 0.5 L bottle of virgin olive oil”. This volume has been chosen because it corresponds to one of the most commonly used capacities in Spain and it is available in the three types of packaging studied. No considerations about the quality preservation (flavor, color, longevity, health qualities, etc.) of the product depending on the packaging material were included in the functional unit. In addition, no differences in product dosage or remains in the bottle were introduced. Therefore, the reference flows for each type of packaging remained the same as the FU.

These, among others, are some of the limitations that VOOs LCAs still have and a thorough study of unsolved issues in VOOs carbon footprint should be performed as it has been for wine (Arzoumanidis et al., 2014).

Data related to some processes were taken from GaBi professional and Ecoinvent databases (Thinkstep, 2015), such as the production of chemicals (insecticides, herbicides, fertilizers), production of diesel, PET, PP and glass and other processes like the landfilling of plastic waste and inert matter.

The agriculture subsystem includes the agricultural field works: application of fertilizers, insecticides, herbicides, and irrigation and harvesting of olives. This life cycle stage does not depend on the type of packaging used for the final virgin olive oils (VOOs) obtained. Inventory data of the agricultural subsystem is presented in Table 3.

Table 3. Inventory data for the agriculture subsystem.

Input	Quantity	Output	Quantity	Comments
[1]Olive Production stage (intensive olive growing)				
Pesticides (insecticides) [kg]	0.01	Olives [kg]	1000	
Herbicides [kg]	0.9	Pruning waste [kg]	714	
Fertilizers [kg]	102			*Fertilizer NPK12-12-24.*
Diesel [kg]	73.21			*LHV(diesel):42.6MJ/kg*
Irrigation water [kg]	1330			*96% of the olive grove is irrigated*
Cultivated land [m^2]	3321.60			
Crop density [olive-tree/ha]	204			
Energy [MJ]	-			

(1) Average data from a published Spanish case study (ECOIL, 2006)

The Oil mill subsystem includes VOOs making and packaging processes. Inventory data for the production of 200 kg average of virgin olive oil from 1000 kg of olives was obtained from the literature (SCP/RAC, 2000). Packaging inventory data was obtained in this study as an average of 10 samples per type of packaging. Inventory data of this subsystem is presented in Table 4. Tin packaging is made of tin coated steel.

Table 4. Inventory data for oil mill subsystem.

Input	Quantity	Output	Quantity	Comments
[1]Oil making with a two-step continuous process (production of virgin olive oil)				
Olives [kg]	1000	Clean water [kg]	125	
Electricity [MJ]	320.4	Watery pomace [kg]	800	*watery pomace: water 60% and oil 3%*
Washing-water [kg]	110	Virgin olive oils (VOOs) [kg]	200	

[2]Packaging stage (0.5L container capacity)

Material	Bottle weight [kg]	[3] Cap weight (PP) [kg]	[4] Oil weight [kg]	Full pack weight [kg]	Observations
Glass	0.449	0.0122	0.461	0.921	*non refillable cap: cap + dispenser.*
PET	0.0263	0.00385	0.461	0.491	
Tin[5]	0.093	0.0037	0.461	0.558	*cap= extensible part + cap*

(1) Average data from Spanish case studies (SCP/RAC, 2000).
(2) Own data from the present study.
(3) Polypropylene (PP) was assumed as the most usual cap material.
(4) Usual density of virgin olive oil: 0.92 kg/L. (Codex Stan 33-1981).
(5) Tin coated steel.

Finally, the third subsystem includes VOOs distribution and end of life stages. The distribution distance considered was an average as explained in section 2.2 (see Table 5).

Table 5. Average distance for distribution considered in the study.

Journey	Distance [km]
Jaén - Barcelona	797.8
Jaén - Madrid	332.7
Average distance	*565.25*

In the end of life stage, depending on the material of the packaging, the percentages of bottles going to recycling or to landfilling are different. These percentages have been taken from usual recycling rates in Spain, according to available information published by the green dot holders (see Table 6). In this life cycle stage, a system expansion was made by including the burdens due to the recycling process together with the environmental credits from the amount of recycled material obtained. It was considered that the recycled material is substituting the corresponding virgin material.

Table 6. Types of waste management depending on packaging material.

Material	Recycling [%]	Landfilling [%]	Reference
Glass	70	30	*ECOVIDRIO, 2015*
PET	63.8	36.2	*ECOEMBES, 2015*
Tin	90.6	9.4	*ECOACERO, 2014*

3.1.2.Environmental impact assessment

The environmental impact of olive production and virgin olive oil making stages is the same for the three different types of packaging studied, and it is only presented once in the impact results (see Table 7).

Figure 2 shows the comparison of the three types of packaging studied for VOOs. The total impact per 0.5 L glass bottle is adjusted to 100% in all impact categories. As shown in Figure 2, strictly speaking, glass packaging has more impact in 9 out of the 12 evaluated impact categories, while tin packaging has higher impact in 2 categories (marine and human toxicity) and PET in 1 (terrestric ecotoxicity, TETP); however, given the uncertainty of life cycle inventory data and life cycle impact assessment models, which we can assume to be no less than 20%, no strong preference statements could be made in six impact categories (only a light indication to be further and more deeply studied).

Figure 3 shows, for glass packaging, the detailed contribution of all life cycle stages in each impact category evaluated. Olive production is the most significant stage in the majority of impact categories (8 out of 12) followed by the packaging stage, which has the highest contribution in 2 categories. On the other hand, the VOOs making stage does not contribute much, having its greater contributions in AP (17%) and water (27%) categories. The distribution stage could be neglected in front of the rest by its little influence. It is important to highlight the negative values for the end of life stage, due to the recycling of the glass (which avoids virgin glass production). For the presentation sake, values below 0.8 have been omitted in Figure 3.

Table 7. Contribution of VOOs life cycle stages in different environmental impact categories for the 3 different bottle types studied (0.5 L capacity).

	GLASS/PET/TIN		GLASS			PET			TIN		
	Life cycle stages in VOOs production system										
Environmental Impact Categories	**Olive Production**	**Olive Oil Making**	**Packaging material**	**Distribution**	**End of life**	**Packaging material**	**Distribution**	**End of life**	**Packaging material**	**Distribution**	**End of life**
Abiotic Depletion (ADP elements) [kg Sb-Equiv.]	1.63E-07	2.21E-08	8,54E-07	2.80E-09	-4,90E-07	2.60E-08	7.68E-10	-5.33E-09	5.38E-08	8.73E-10	-3.78E-09
Abiotic Depletion (ADP fossil) [MJ]	11.359	1.068	6,120	0.428	-0,953	2.282	0.228	-0.574	2.669	0.259	-0.180
Acidification Potential (AP) [kg SO2-Equiv.]	9.10E-04	4.79E-04	0,002	1.30E-04	-9,32E-04	1.23E-04	7.41E-05	-2.64E-05	6.44E-04	8.42E-05	-4.64E-05
Eutrophication Potential (EP) [kg phosphate-Equiv.]	2.83E-04	2.97E-05	2,78E-04	3.25E-05	-1,38E-04	1.45E-05	1.87E-05	-3.10E-06	4.49E-05	2.13E-05	-3.16E-06
Freshwater Aquatic Ecotoxicity Pot. (FAETP inf.) [kg DCB-Equiv.]	4.63E-03	2.39E-04	6,70E-04	1.78E-04	1,90E-04	5.72E-04	1.84E-04	-1.43E-04	6.34E-04	1.35E-04	-4.23E-05
(1)Global Warming Potential (GWP 100 years) [kg CO2-Equiv.]	0.407	0.087	0,421	0.031	-0,080	0.085	0.017	-0.018	0.245	0.019	-0.017
Human Toxicity Potential (HTP inf.) [kg DCB-Equiv.]	0.028	0.006	0,008	0.001	0,004	0.003	6.63E-04	-0.001	2.22E-02	7.54E-04	-0.002
Marine Aquatic Ecotoxicity Pot. (MAETP inf.) [kg DCB-Equiv.]	16.033	6.378	10,100	0.444	6,300	2.840	0.248	-0.520	42.318	0.282	-3.097
Terrestric Ecotoxicity Potential (TETP inf.) [kg DCB-Equiv.]	4.59E-03	8.68E-05	3,19E-04	5.12E-05	-7,09E-05	2.44E-03	1.22E-04	-0.001	4.88E-04	1.38E-04	-2.06E-05
Primary Energy [MJ]											
Energy total (net cal. value)	12.274	2.168	6,980	0.452	-0,717	2.375	0.242	-0.578	2.917	0.275	-0.198
Energy nonrenewables (net cal. value)	11.606	1.534	6,570	0.430	-0,609	2.329	0.229	-0.575	2.849	0.260	-0.193
Water Consumption [kg]											
Water	1.681	0.856	0,945	0.041	-0,301	0.346	0.023	-0.073	0.036	0.026	-0.00017

(1) excluding biogenic carbon

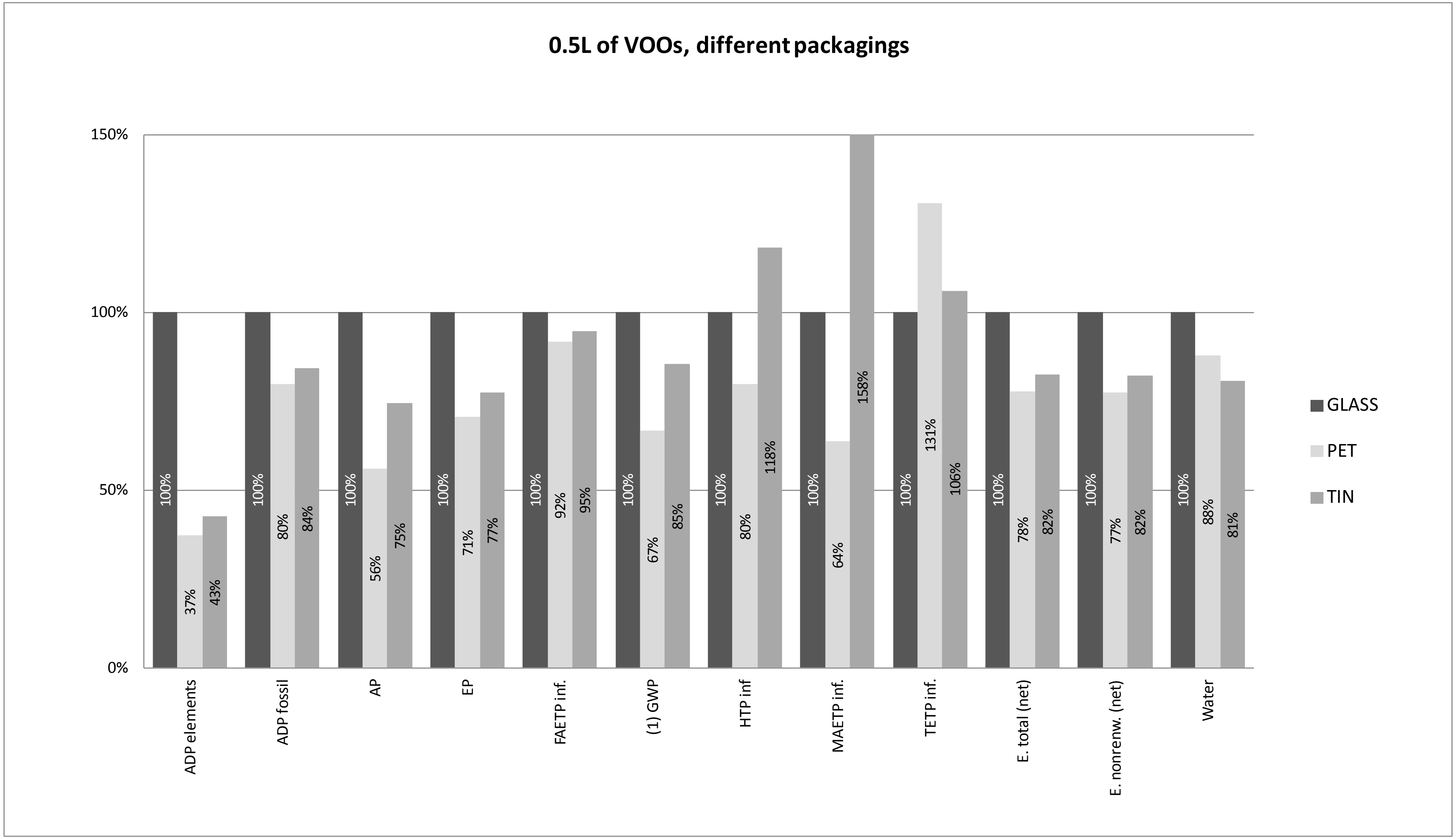
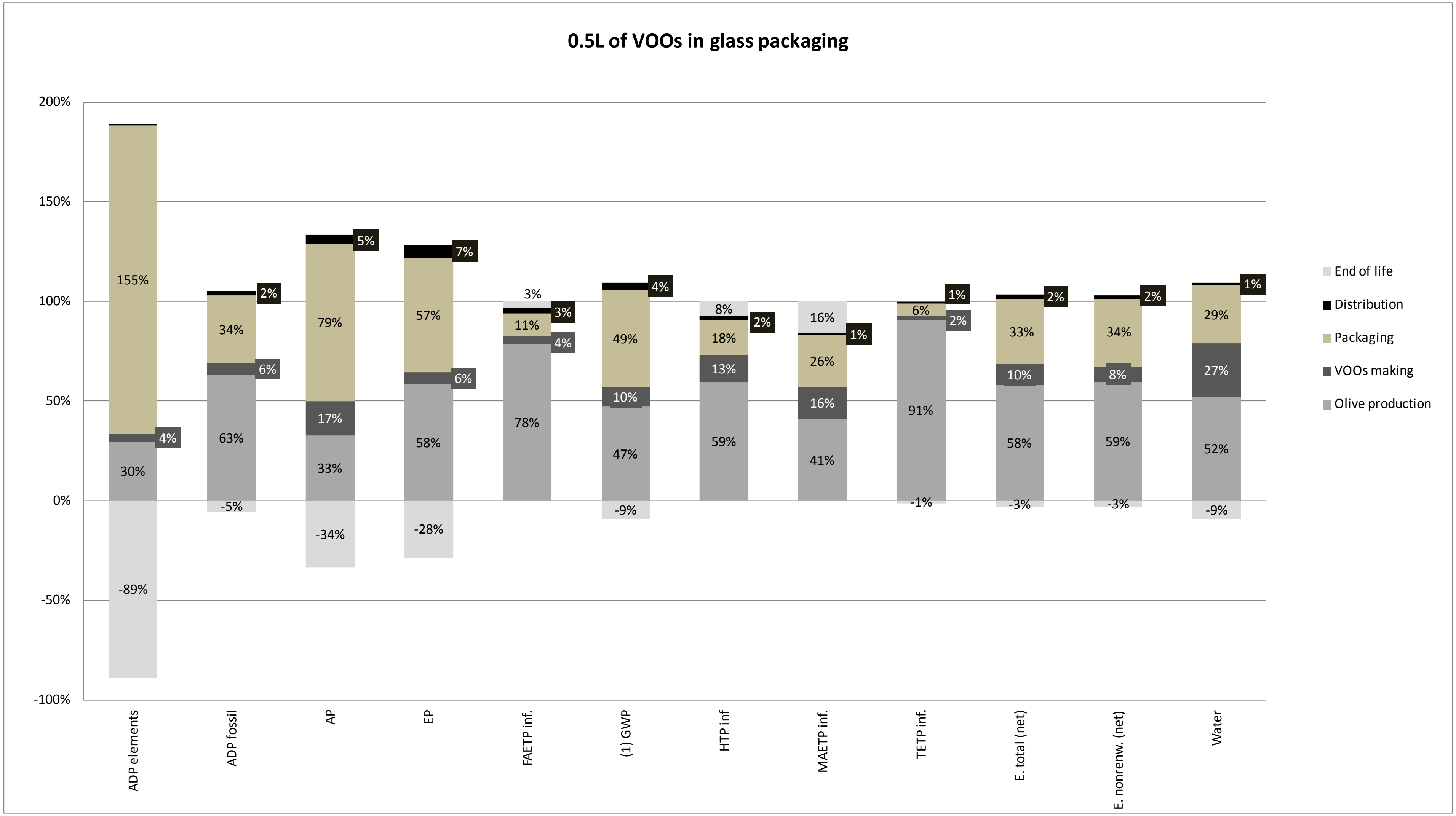


Fig. 2. Comparison of the environmental impact of three different types of 0.5 L bottles of VOOs. Glass packaging impact value adjusted always to 100%.



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308 **Fig. 3.** Percentage contribution of 5 VOOs life cycle stages (olive production, VOOs making, packaging, distribution and end of life) in the different impact categories
309 assessed. A 0.5 L glass bottle is considered.

3.1.3.Assessment details.

The results per life cycle stage shown in Table 7 are summarized in Table 8. Olive production is the most contributing stage for the 3 types of packaging under study, followed by the packaging stage. Within the olive production stage, the most contributing aspect in most of the impact categories is the production of the diesel used for agricultural works. Within the packaging stage, the most contributing aspect is the production of the packaging material and it is proportional to the packaging weight which, for image reasons, tends to be quite high in restaurants application, because weight and design is identified as a high quality factor. Finally, within the oil-making stage, the most contributing aspect is usually electricity production.

Table 8. Main detailed results.

Life cycle stage	Type of packaging	Impact categories
Olive production has the highest contribution to most impact categories	In all the 3 types of packaging	8 categories in Glass packaging 11 categories in PET packaging 11 categories in Tin packaging
Olive production stage has a similar value as the packaging stage	Glass packaging Tin packaging	*EP and GWP* *HTPinf.*
The packaging stage has a higher impact value in:	Glass packaging Tin packaging	*AP, ADPelements and GWP* *MAETPinf.*
End of life stage has usually a negative contribution to all categories (due to recycling) except:	Glass packaging	*FAETPinf.* , *HTPinf.* and *MAETPinf.*

Table 9 was elaborated in order to more clearly visualize the environmental impact contribution of the packaging to the system by each type of packaging. It is very important to state that, in principle, the packaging function is to preserve the product; therefore, it is a component which makes the system's impact to diminish. However, this effect upon the product system is not the aim of this study to determine. We will only study the negative effects of the packaging participation.

First column of Table 9 offers the impact results for the product (without packaging; i.e., olive production, olive oil making & olive oil distribution) normalized to 100%. The rest of the columns present results for different types of packaging, by combining the three life cycle stages affected by the type of packaging: packaging production, packaging distribution and end-of-life. Thus, the packaging adds a percentage of impact to each impact category. This added impact is between 6% and 196% for glass packaging, between 4% and 38% for PET and between 2% and 174% for tin. As shown in Table

9, the added impact due to packaging is high in some impact categories. This is in accordance to our findings in the wine sector (Gazulla et al. 2010; Navarro, et al., 2017a; Navarro, et al., 2017b) and to other beverage and food products literature (Pattara, et al., 2012; Flanigan et al., 2013).

It has to be noted that the distribution stage has been split in two parts: product distribution (which was included in first column of Table 9) and packaging distribution (included in the impact contribution due to the type of packaging)..

Table 9. Additional impact (in %) due to different types of packaging in VOOs life-cycle results.

Environmental Impact Categories	**Olive Production + VOOs Making+ VOOs distribution[a] [%]**	**GLASS (450g/bottle)**	**PET (26.3 g/bottle)**	**TIN (93 g/bottle)**	**GLASS (300g/bottle)**	
					virgin	**50% recycled**
		Additional impact due to packaging type				
		Packaging +Distribution[b] +End of Life [%]				
Abiotic Depletion (ADP elements) [kg Sb-Equiv.]	100	196%	11%	27%	87%	52%
Abiotic Depletion (ADP fossil) [MJ]	100	43%	14%	20%	29%	28%
Acidification Potential (AP) [kg SO2-Equiv.]	100	91%	7%	42%	51%	42%
Eutrophication Potential (EP) [kg Phosphate-Equiv.]	100	47%	4%	14%	25%	19%
Freshwater Aquatic Ecotoxicity Pot. (FAETP inf.) [kg DCB-Equiv.]	100	19%	9%	13%	15%	16%
(1)Global Warming Potential (GWP 100 years) [kg CO2-Equiv.]	100	70%	13%	45%	46%	43%
Human Toxicity Potential (HTP inf.) [kg DCB-Equiv.]	100	36%	8%	60%	26%	28%
Marine Aquatic Ecotoxicity Pot. (MAETP inf.) [kg DCB-Equiv.]	100	73%	10%	174%	55%	59%
Terrestric Ecotoxicity Potential (TETP inf.) [kg DCB-Equiv.]	100	6%	38%	12%	4%	3%
Primary Energy [MJ]						
E. total (net cal. value)	100	44%	12%	19%	31%	30%
E. nonrenewables (net cal. value)	100	46%	13%	20%	32%	32%
Water Consumption [kg]						
Water	100	26%	11%	2%	17%	15%
Average of additional impact due to packaging		*58%*	*13%*	*37%*	*35%*	*30%*

(1) excluding biogenic carbon
[a] VOOs Distribution, without packaging (500mL of VOOs alone).
[b] Distribution, of empty container

As eco-design alternatives, the last two columns of Table 9 are calculated using 300 g per glass bottle instead of 450 g, which is the most widely used and last column uses 50% recycled glass in the bottle. The comparison of the two different weights of glass bottle (450 g or 300 g) will be explained in the following section.

The most relevant conclusions taken from Table 9 are the following:

1. Glass and tin packaging are the ones adding more impact (average of 58% and 37% respectively) to most of the impact categories, while PET adds about 13% of impact.
2. The added impact for glass packaging is more category dependent than for tin and PET.
3. Impact added by PET packaging is lower, mainly due to its lower weight.
4. It is important to keep in mind that the beneficial consequences of using packaging (compared to distributing in bulk) to preserve the product are not studied here.

3.1.4. Recommendations for packaging improvement

According to our previous results, PET packaging seems to be the best option for VOOs, although to preserve the quality of the product (VOOs) and to be attractive to consumers (by reflecting its status of a high quality product) it is necessary to evaluate a set of other additional factors (quality preservation, longer life, regulatory compliance, marketing, etc.).

Some published papers study the effect of certain factors related to the packaging in the VOOs quality (Pristouri et al., 2010). Some of the studies developed a method to measure VOOs oxidation (Kanavouras et al., 2004; Cecchi et al., 2006) or mathematical predictive models (Coutelieris et al., 2006). Studies of different shape, colour (Guil et al., 2009; Rizzo, et al., 2014), and type of packaging material (Méndez et al., 2007; Parenti, et al., 2010) and their effects on the time of storage have been made. They conclude that light, oxygen, humidity and temperature (Tsimis et al., 2002; Sacchi, et al., 2008) have a negative effect in the VOOs quality preservation and product deterioration occurs when exposed to these conditions during storage. Therefore, dark colored materials are advisable as well as materials with lowest or no transmission of particles by contact with the VOOs (ie. glass is the most inert material in this case).

In relation to the market image, consumers tend to relate design, type of material and also weight as a distinctive of higher quality. This is the reason why the glass bottle is usually the most generally used for VOOs in the main consuming markets, except Spain (Linares et al., 2006), where the PET bottle is the most commercialized.

In the case of glass packaging, some improvements could be made:

1. Avoiding luxury bottles with a high weight of material (see Figure 4).

Fig.4. Glass bottle of olive oil (500mL).
(Source[4]: Pérez Campos, 2017).

2. Reducing the weight of the glass bottle from the most common 450g per 500mL bottle to lighter bottles weighting about 300g (see impact results decrease in Table 9). Table 10 shows wide margins of glass-bottle weight that can be found in the market compared to the other packaging materials. This bottle-weight-reduction trend has been followed by the wine and cava markets (Navarro, et al., 2017a), in order to decrease their impact on climate change.
3. Using a higher percentage of recycled glass in VOOs glass-bottles (see last column in Table 9).

Table 10. Packaging weights (500mL) of different materials

Material	(1) PACKAGING WEIGHT [g]			Comments
	Range	Commonly used	Extreme values	
Glass	300 - 750	450, 460	260, 850	In the market, more variation of designs and weights
PET	24 - 26			Short variation (specially in weight)
Tin	62 - 98	83		Short variation

(1) Data obtained from VOOs producers and packers and from experimentally weighting 10 samples of each type found in the market.

The minimum value of the usual range of glass-bottle weight (300 g/bottle) has been used to evaluate again the environmental profile of VOOs life cycle and the main results are shown in last two columns of Table 9. This 33% weight reduction is fairly influential. High impact reductions in packaging influence (of 109% and 40%) were obtained in ADP elements and AP respectively, together with lower reductions in other impact categories. Greater impact reductions would be obtained when increasing the percentage of recycled glass used in the VOOs glass bottles (see last column of Table 9). Green and brown glass (the ones more suitable for VOOs bottles) are able to include around 50% recycled glass, while white glass only accepts about 15% (Álvarez C., 2012). In this case, to calculate the impacts avoided by the recycled glass obtained in the end-of-life stage, the hypothesis taken was

[4] Vidrierías Pérez Campos: http://www.perezcampos.es/botellas-de-aceite-oneros-500-oscura.html

that the recycled glass would avoid the same percentages used for the production of the bottle (50% virgin and 50% recycled glass).

3.2. Environmental consequences of the Spanish regulation RD 895/2013

3.2.1. Goal and scope

HORECA supply chain consumes about 11.3% of the global olive oil consumption in Spain (43.5% in restaurants; 36.5% in bars; 14.1% in hotels and 5.9% in other establishments) (ADCA, 2009). The intended application of this study is to assess the environmental consequences of the non-refillable-VOOs-dispensers regulation affecting HORECA supply chain in Spain. The reason for carrying out this study is, with a simple exercise, to show Spanish policy makers how LCA can be used to measure the environmental consequences of their decisions (Fullana-i-Palmer et al., 2011). It is important to notice that this regulation was deeply discussed at European level and submitted to public consultation, but finally it was withdraw by the EU (due to rejection from consumers) and it was only implemented in Spain (Telegraph, 2013).

Figure 5 shows the two systems being compared and the life cycle stages included within the boundaries: system 1, the original one, and system 2, the one after the regulation. The end-of-life stage includes both recycling and landfill processes (percentages are shown in Table 7). The avoided impacts due to the obtained amount of recycled material were also considered (following the same hypothesis described in section 2.2 for the end-of-life stage).

The function of both systems was to deliver VOOs to the HORECA sector. The chosen functional unit was: the total amount of VOOs consumed in restaurants in Spain during one year. As reference flow, for System 2, being the first year of application of the regulation, the year 2014 consumption was taken from Table 3, i.e., 56966854 L of VOOs. For system 1, as explained below, a 2% reduction was applied, resulting in a reference flow of 55827517 L of VOOs.

One single impact category was used as environmental indicator. Global Warming Potential (GWP) was chosen as environmental indicator because it is the most widely used proxy nowadays (Bala et al, 2010). No critical review was performed.

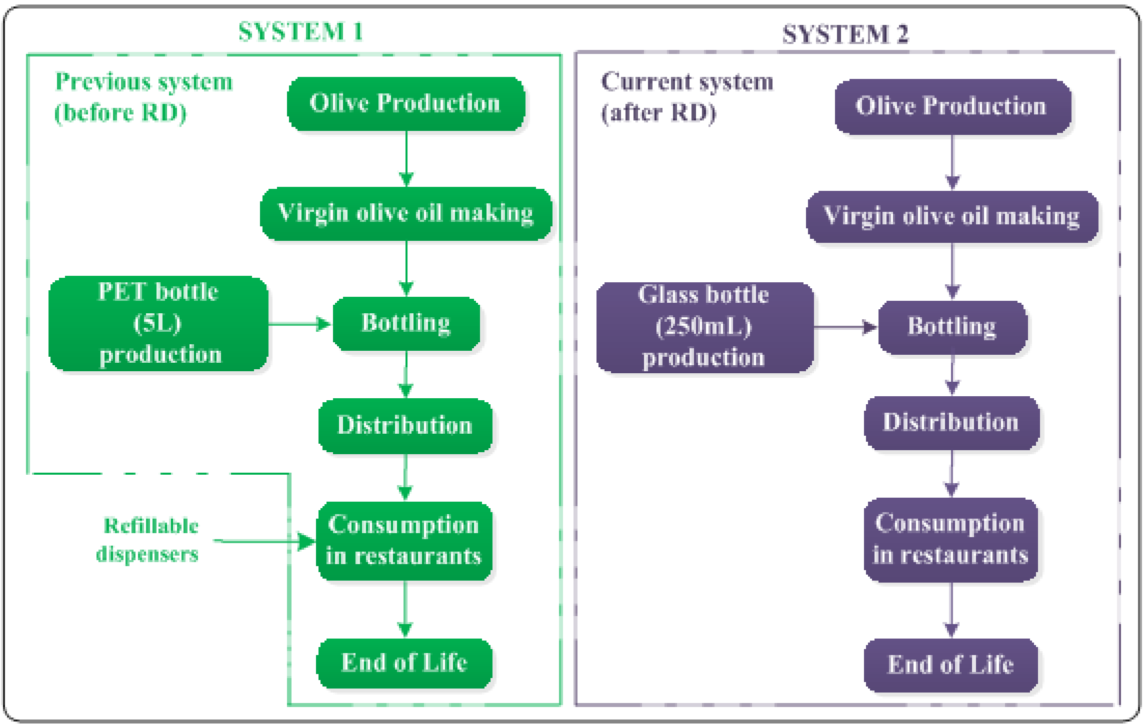

Fig.5. System boundaries of the two compared scenarios.

3.2.2. Inventory analysis

In order to get direct data from restaurants, a questionnaire was developed. Average results from questionnaires answered by 20 restaurants are presented in Table 11. The main conclusions from the questionnaires related to the RD are the following:

1. About 50% of restaurants agree with the regulation, stating that customers may then exactly know the quality of the VOOs consumed and that the consumption action is cleaner with this kind of packaging. The main drawback is the increase of costs (3 times more expensive) due to the consumption of higher quality VOOs and the use of more sophisticated packaging.
2. Some of the restaurants (about 35%) report that they don't follow the regulation. They are refilling the non-refillable VOOs bottles.

3. Some of those restaurants not happy with this regulation make special sauces by mixing VOOs with some herbs or they dress the courses in the kitchen, before serving them to the customer. This way, they avoid the use of non-refillable oilers on the table.
4. None of the restaurants reported a collection based on Deposit Refund System (DRS). Although 30% of glass packaging is not paying the "green dot" of the EPR collection system and should be adhered to a DRS, they use the EPR or the general waste containers.
5. All in all, it seems that the RD is not being properly followed and that some actors in the chain may be more affected than others. In order to have a better packaging design to fulfill the technical requirements as well as being more sustainable, an eco-design activity through a product panel where all actors participate may be a good solution (Watson et al., 2011).

Table 11. Summary of restaurant answers to the questionnaires

GENERAL INFORMATION		
Question	**Results**	**Comments**
Name of the restaurant	-	
Location	Spain	
Type of local (restaurant, snack bar, bistro bar)	restaurants 93%	
Type of service (snacks, menu, tapas, etc)	Menu: 93%	usually
Capacity	79	average
Contact person	Owner or worker	
Are you registered in the HORECA supply chain? (yes/no)	20% Yes	
Do you collect separately the packaging for recycling? (yes/no)	75% Yes	
a. Do you throw the empty VOOs bottles to the street container for glass?	93%	Related to the % that answered yes in previous question (75%)
b. Or is your distributer who picks up your empty VOOs bottles?	none	Although 30% has no green dot!
SPECIFIC INFORMATION OF PACKAGING PER YEAR		
Question	**Results**	**Comments**
AFTER the use non-refillable oilers		
Type of packaging used as dispenser of VOOs:		
Material	98% Glass	The rest (2%) uses PET
Capacity [L]	78% 0.250 L	The rest (22%) uses a 0.5 L bottle capacity
Expenditure (€/ bottle)	Average: 3.7 (0.250 L)	Range: 1.30-7.50
How much more VOOs do you use now? (estimated %)	Average: 3%	Range: 1-10%
Does the packaging have the "green dot"?	70% Yes	
BEFORE the use non-refillable oilers		
Type of packaging used as dispenser of VOOs:		
Material	100% PET	
Capacity [L]	90% of 5 L	
Expenditure (€/ bottle)	Average: 25 (5 L)	

The inventory data needed for the study was:

- The VOOs consumption for both systems (system 2 has an increase of VOOs consumption due to the amount of product disposed with the packaging).
- The type and amount of the packaging used (system 2 uses 250 mL glass-bottles and system 1 5 L PET-bottles).
- Distribution average distance of 565 km (see Table 6) was considered.

Results from questionnaires (Table 12) were used in those calculations, together with the total amount of VOOs consumed in Spanish hospitality sector in 2014 (see Table 3).

To estimate the increase of VOOs consumption after the application of the regulation (system 2), 15 discarded VOOs-bottles were collected in 15 restaurants and the remaining VOOs weight to be discarded with the packaging was measured. The result was that an average of 2% of the VOOs content was going to be discarded (percentage slightly lower than the average 3% obtained from the questionnaires). A 2% decrease in system 1, compared to system 2, was considered in the calculations (for VOOs consumption), because the amount of VOOs discarded with 5L PET bottles was negligible. The inventory data used in the study is shown in Table 12.

Table 12. Inventory data used to calculate the carbon footprint of VOOs consumption in restaurants before and after RD 895/2013 regulation.

Aspects	Data per 1 year (VOOs consumed in Spanish restaurants)		
	System 1 **Before** RD	System 2 **After** RD	Comments
Reference flow: Total consumption VOOs [L]	(2)55 849 857	(1)56 966 854	2% of VOOs is over-consumed after RD application compared with before, due to VOOs which remains in the bottom of the bottles when they are discarded.
Number of glass bottles (250 mL) per year		227 867 416	Total consumption VOOs (after RD) / 250mL
Number of PET bottles (5 L) per year	11 169 971		Total consumption VOOs (before RD) / 5L
Weight of a glass bottle (250 mL) [g]		300	Average among most common bottles (from 10 samples)
Weight of a PET bottle (5 L) [g]	207		Average among most common bottles (from 10 samples)

(1) Value obtained from available information of 2014 (see Table 3)
(2) Value estimated by applying a 2% reduction in total VOOs consumption of system 2. This value (2%) was obtained experimentally: by weighting the VOOs remaining in the bottle to be discarded (calculated from a sample 15 VOOs non-refillable glass dispensers)

3.2.3. *Environmental impact results*

GWP environmental impact was assessed by using inventory data shown in Table 12. Emission factors for the production of VOOs and for the production of glass and PET bottles were taken from the present study and from databases (Thinkstep, 2015).

Results show a 74% increase of the carbon footprint of system 2 (after RD) compared with System 1 (before RD) (see Figure 6), from 6.20E+07 kg of CO_2-eq before RD (system 1) to 10.8E+07 kg of CO_2-eq after RD (system 2). This 46000 t CO_2-eq increase along the system's life cycle is equivalent to the 0.014% of the Spanish annual direct CO2-eq emissions (MAPAMA, 2016) (329E+06 brut tonnes CO_2eq, excluding land use, land use change and forestry) or equivalent to 0.0155% of 297.5E06 net tonnes of CO_2eq (including land use, land use change and forestry). Being only related to such a small sector of activity, the contribution seems to be quite relevant.

Fig.6. GWP (carbon footprint) results of both systems compared (results in %).

These results are based on the assumptions made to calculate: the consumption of VOOs per year in hospitality sector; the percentage (%) of VOOs remaining in the current glass-bottle packaging and the amount of packaging used and their weight. Therefore, results obtained have some uncertainties due to lack of specific data, because restaurants are not commonly used to measure and report, among others, the amount of VOOs consumed and the packaging discarded to the waste collection system.

Nevertheless, We think that, in spite of the uncertainties, the results show a clear increase of the impact to be taken into account for future improvements.

It is strongly recommended to perform life cycle assessments (at least simplified studies, like the present one) before implementing any type of regulation at national and international level, to prevent unwanted environmental consequences.

4. Conclusions

Packaging has an important contribution in the life cycle of VOOs, being from 2% to 196% of the environmental impact of the product, depending on the impact category considered and the type of packaging. The type of packaging used affects three life cycle stages: bottling (where the production of the bottle is considered), distribution (influenced by the weight and robustness of the bottles) and end-of-life (where the recycling rate is important). The contribution of the 3 main types of primary packaging (glass, PET and tin) within the whole VOOs life cycle is presented for the first time in the literature.

Glass bottles are the option which produces the highest impacts, shortly followed by tin (with the hypothesis of the present study: 450 g per glass bottle, 26.3 g per PET bottle and 93 g per tin bottle; all bottle capacities being of 500 mL).

Glass bottles are the most commonly used because of several reasons related to real and perceived quality by the customers: elegance, purity, preservation, design, cleanness, etc. These properties have not been included in the functional unit of the study. Being used because of this differentiation, in order to reduce the environmental impact of using glass bottles for VOOs, a reduction of the bottle weight is suggested (at least to 300 g/bottle), together with the use of a higher percentage of recycled glass.

The Spanish regulation for public establishments (RD 895/2013), related to the mandatory use of non-refillable-oilers, has caused a significant 74% increase of environmental impact (measured as CO2-eq emissions), due to the higher amount of packaging required and to the quantity of VOOs discarded with the packaging at the end of its life. In spite of the uncertainties of these results (due to lack of more accurate data), the environmental consequences of this regulation (which are evaluated and published for the first time) need to be taken into account for ecodesign improvements of the packaging. Nevertheless, these results are a first estimation and further research would be needed to have more accurate results to be used at political decision making level.

Another consequence of this regulation was the increase of price per service (3 times higher, estimated in the present study, and 7 times higher, according to the hospitality sector (InfoHoreca, 2016)). Because of this, some restaurants are trying to avoid this regulation by using additive ingredients (herbs, garlic, etc.) mixed with the VOOs to make especial sauces, or by dressing the courses in the kitchen, or even refilling the un-refillable dispensers (in lower quality restaurants). Only about 50% of the restaurants answering a questionnaire agreed that the regulation was a wise choice because the product is cleaner and shows the exact quality of the VOOs used. It is clear from our point of view that before implementing a regulation (which, by the way, had been previously rejected at EU level) a fair estimation of environmental and social consequences, like the ones discussed here, should be studied so that recommendations to reduce its bad effects could be included in the text of this regulation.

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